

EFFECTS OF DAMS ON BEACH SAND SUPPLY

by

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INTRODUCTION

In 1975 a regional sediment management study was initiated as a joint applied research project of the Environmental Quality Laboratory, California Institute of Technology, and the Shore Processes Laboratory, Scripps Institution of Oceanography. The project is a broad-based, long-term multidisciplinary effort intended to define the regional sediment budget for coastal Southern California (Figure 1), and to quantify the effects of various human activities on changes in that budget.

One of the primary elements of this project is to define quantitatively the natural sediment-transport regimen of streams and the specific effects of human controls on that regimen. As a means to accomplish these goals, nine major rivers draining to the shoreline in the project study area were identified for primary analysis. These rivers are the Ventura, Santa Clara, Los Angeles, San Gabriel, Santa Ana, Santa Margarita, San Luis Rey, San Diego, and Tijuana (Figure 1), which collectively drain about 72 percent of the study area. Other rivers were initially deleted from consideration because of a lack of appropriate data or because they flowed into a lagoon or bay and lacked the potential for direct contribution of sand to beaches. The study of the nine major rivers intends to quantify the beach-sized sediment delivery to the shoreline each year from 1925 to 1975 and estimate the sediment deliveries that would have taken place without the construction of flood-control and water-conservation structures and other facilities during that period. The 1925-75 period was chosen because it was during that period that most of the significant human construction in Southern California took place, and also because almost all of the

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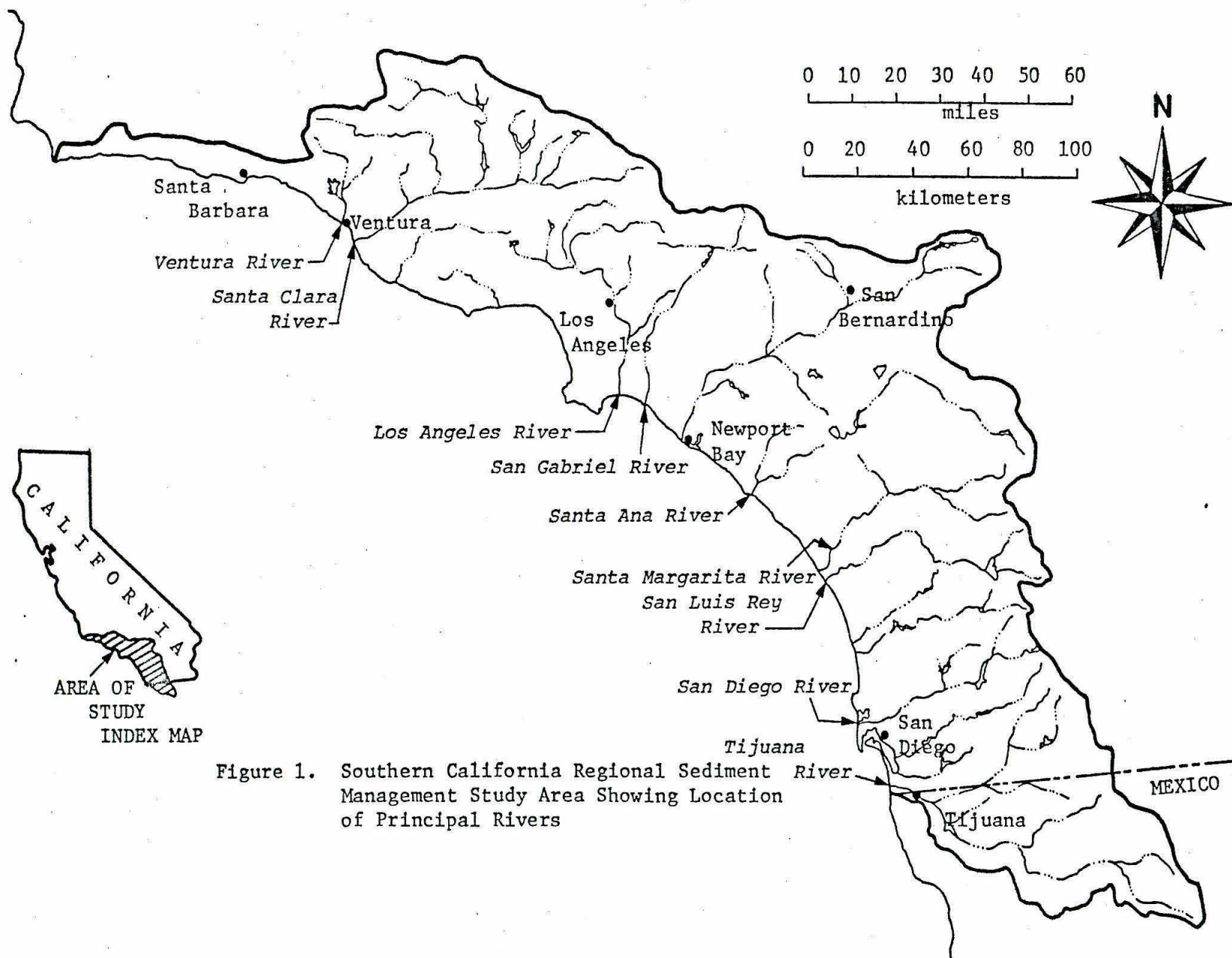


Figure 1. Southern California Regional Sediment Management Study Area Showing Location of Principal Rivers

historical streamflow and sediment discharge data was collected during that time.

This report addresses general concepts of studies on the nine major rivers and outlines work completed to date on the Ventura and Santa Clara Rivers. Work on the remaining rivers is in progress, and is intended for completion by mid-1978.

VENTURA RIVER

The Ventura River (Figure 2) drains 585 square kilometers of hilly and mountainous terrain, and discharges to the shoreline just west of the city of Ventura. Annual precipitation on the basin ranges from about 40 centimeters near the Pacific coast to more than 80 centimeters in the mountainous headwaters. The basin is underlain primarily by steeply dipping and heavily fractured sedimentary bedrock upon which thick colluvial and landslide deposits have developed. The vegetal covering is a fairly uniform mantle of chaparral and oak woodland except in the highest parts of the basin where there are extensive rock outcrops. The dominant cultural features in the basin include Matilija and Casitas Reservoirs, and orchards and suburban tracts along the main river and in a broad valley near Ojai.

The Ventura River basin, northwesternmost of the nine major study basins, was selected for the first attempt at sediment yield modeling. The relatively small size, good data base, and clarity of the control history of the basin provided the basis for a relatively straightforward statistical model of the effect of control structures on sediment delivery to the ocean.

The strategy of sediment yield modeling on the Ventura River had three major steps. These were (1) determination of the effect of control structures on the annual volume of streamflow discharged to the ocean, (2) establishment of a mathematical relation between streamflow and sediment discharge, and (3) combination of the results from steps (1) and (2) to produce both estimates of actual sediment yield, and sediment yield as it would have occurred if the control structures had not been built.

The basic technique for step (1) of the modeling was a double-mass analysis. This technique, as it applies to the Ventura River, is illustrated in Figure 3. The cumulative annual discharges for the two stream gauging stations shown on Figure 2 have been plotted for the period 1934-75. Matilija Creek is an uncontrolled stream above the point where it is gauged, and the Ventura River at its gauged location is controlled by the two major reservoirs. The initial section of the curve of Figure 3 represents the period 1934-48 when human influence on runoff was minor. The correlation between the cumulative discharges of the two stations is very high ($r = 0.997$) for this part of the curve which is represented as a straight line. The extension of that line (dashed) provides an estimate of the expected cumulative annual discharges of the Ventura River without the influence of control structures. The effects of the structures on cumulative annual discharge

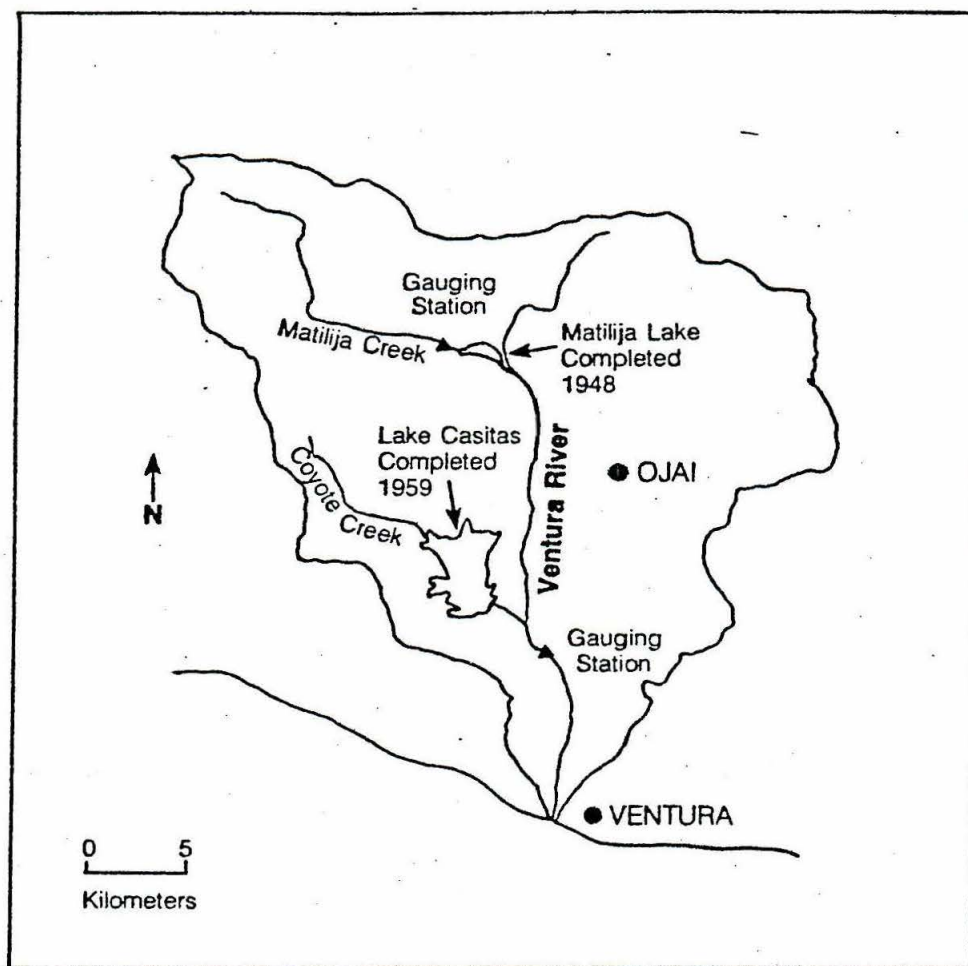


FIGURE 2. Map of Ventura River Basin Showing Locations of Principal Control Structures

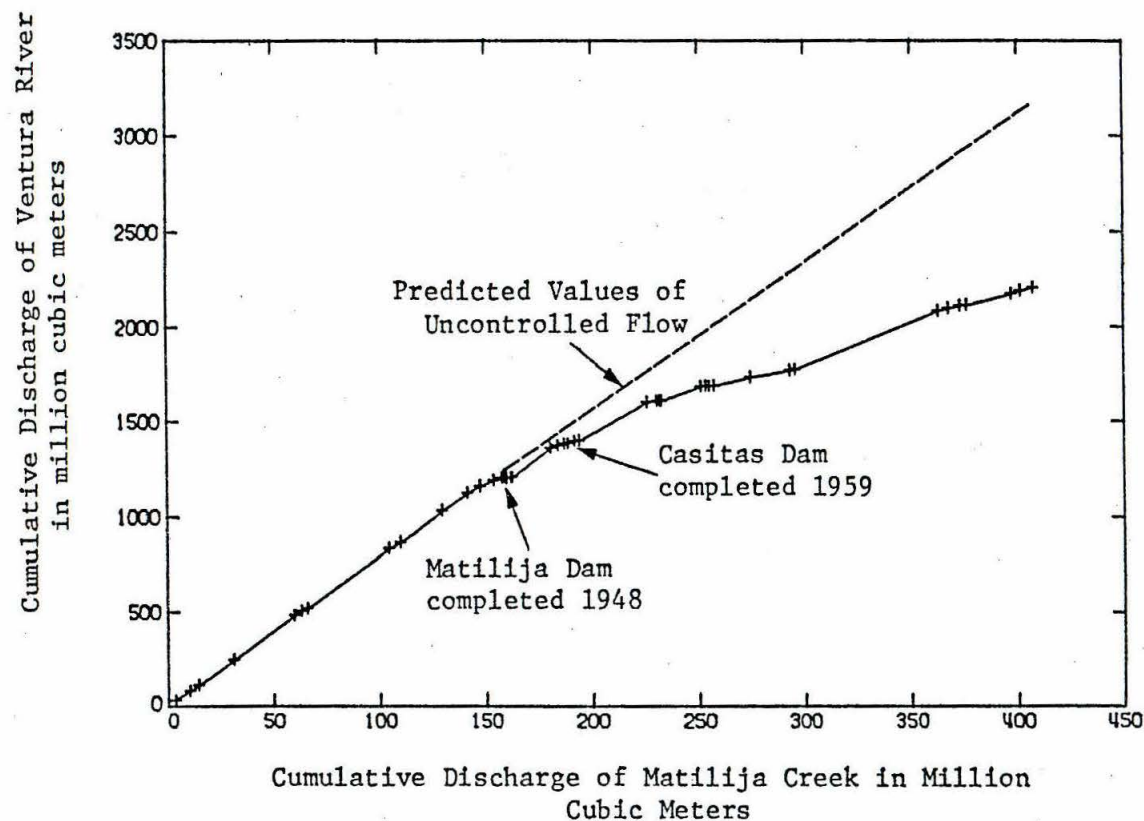


Figure 3. Double-mass relation between flows of Matilija Creek (uncontrolled) and the Ventura River (controlled since 1948) for the period 1928-75.

are shown by breaks in the curve that represent the times of completion of the structures. Data used to construct the curve indicate the following: (1) With the completion of Matilija Dam in 1948, the total runoff from the Ventura River between 1948 and 1958 was reduced 26 percent, and (2) with the completion of Casitas Dam in 1959, total runoff for the years 1959 to 1975 was further reduced to a total of 53 percent.

Figure 4 shows the relation between annual streamflow and sediment discharge for the downstream station on the Ventura River for the period 1969-73 and 1975 (data were not collected in 1974). Despite the paucity of data, the relation is well-defined and extends over a wide range of annual flows. Note that the relation is non-linear such that doubling the annual streamflow would approximately triple the annual sediment discharge. The application of the relation of Figure 4 to the expected and actual flows determined by the double-mass analysis completes the basic modeling procedure. The computations show that, with the completion of Matilija Dam in 1948, there was a 21 percent reduction in the sediment discharge of the Ventura River between 1948 and 1958. With the completion of Casitas Dam in 1959, the sediment discharge was further reduced to a total of 66 percent of predicted uncontrolled sediment discharge for the period 1959-75. As the study continues, the analysis will be further refined to produce estimates of absolute quantities of beach-sized sediment deliveries.

SANTA CLARA RIVER

The Santa Clara River (Figure 5) drains a basin of 4,219 square kilometers, the third largest of the nine major study basins. The river originates in Soledad Canyon east of Newhall and thence flows westerly about 110 kilometers to its mouth just south of Ventura. Annual precipitation ranges from about 20 centimeters in the easternmost part of the basin to more than 100 centimeters in the mountains north of Santa Paula. The basin is underlain by intensely folded and fractured sedimentary rocks in the western parts, highly fractured metamorphic rocks in the northeastern parts, and heavily fractured granitic rocks in the southeastern parts and in the headwaters of Piru Creek. The mountainous parts of the basin are dominantly mantled with chaparral, and pockets of conifer and broadleaf evergreen forests grow in sheltered canyons and at higher altitudes. Grass and low shrubs constitute the sparse vegetation southeast of Bouquet Reservoir on both sides of Soledad Canyon. Orchards and other crops cover the flood plain and hills adjoining the main Santa Clara River channel, and a dense riparian growth borders many parts of the channel.

The principal tributaries to the Santa Clara River are mountain streams that enter from the north. Southern tributaries are short and drain only a small area of the basin. The northern tributaries flow in narrow, bedrock-confined channels having steep gradients. Along a mountain front that parallels much of the Santa Clara River, these channels change abruptly into alluvial channels of lesser gradient before merging with the main river channel. This latter channel is a broad, braided, alluvial channel for much of its length in contrast to the confined channels that feed it.

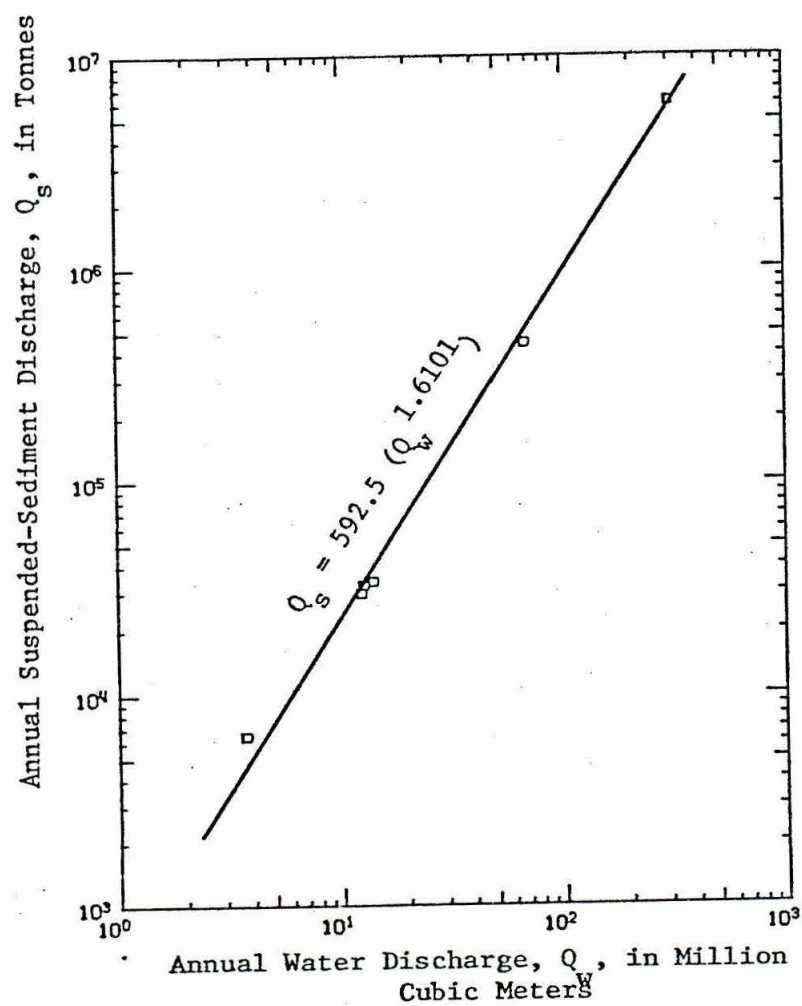


Figure 4. Sediment-transport relation for the Ventura River (USGS Gauging Station 11118500) for water years 1969-73, 75.

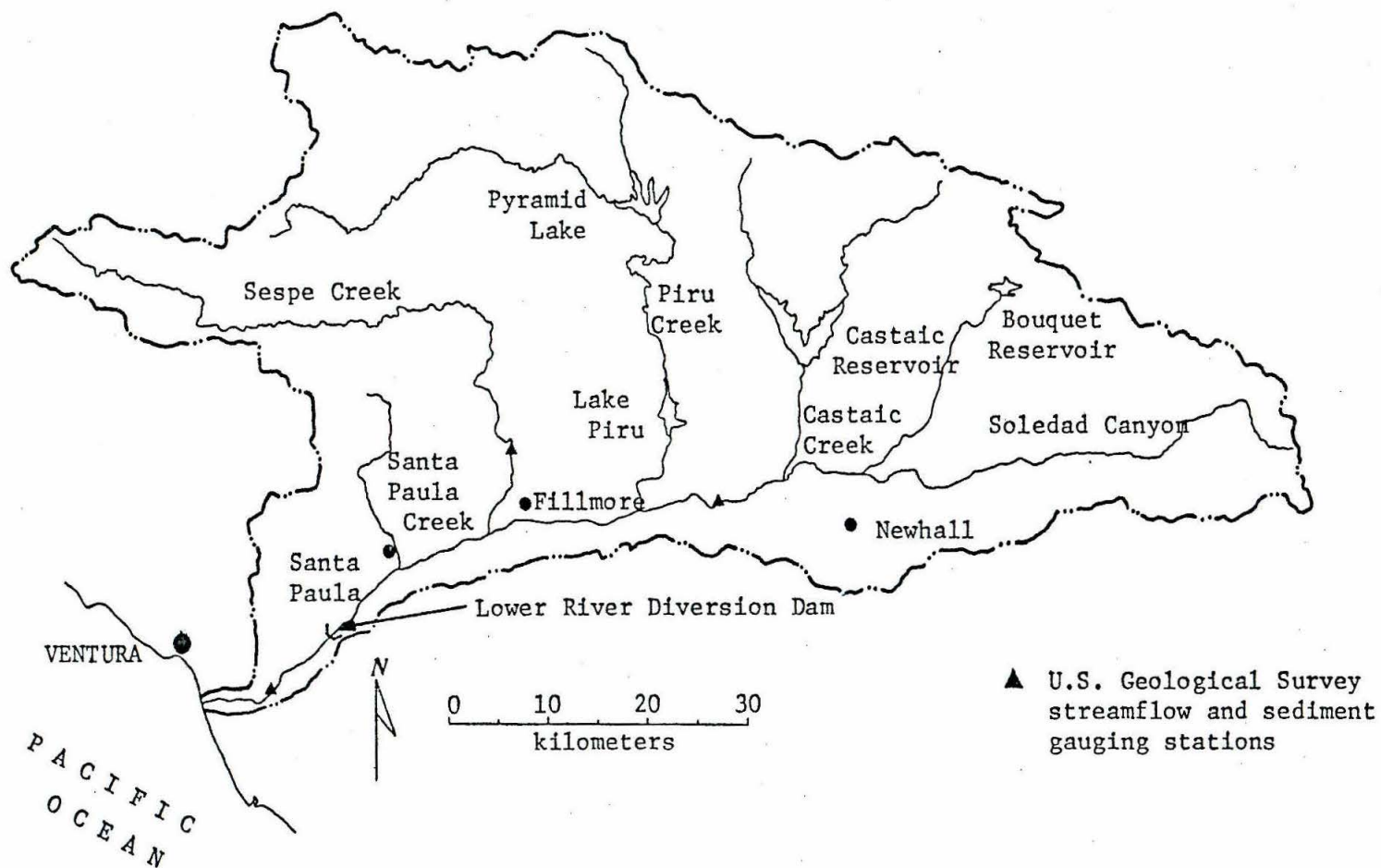


Figure 5. Map of Santa Clara River Basin showing locations of principal control structures

Major structural controls on channels in the basin include Santa Felicia Dam (Lake Piru) and Pyramid Dam on Piru Creek, Castaic Dam on Castaic Creek, Bouquet Canyon Dam on Bouquet Creek, and the Lower River Division Dam on the Santa Clara River (Figure 5). Lake Piru was designed to impound runoff from within the basin. Bouquet Reservoir receives water imported by canal and pipeline from eastern California (Owens Valley). Pyramid Lake receives water imported by canal and pipeline from Northern California, and the water is then transported through a tunnel to Castaic Lake. Releases are made from Bouquet Reservoir and Castaic Lake for water supply for the Los Angeles metropolitan area to the south. Releases into Piru Creek from Pyramid Lake are also made to augment flow into Lake Piru. Releases from Lake Piru plus intervening tributary flow are diverted at the Lower River Diversion Dam primarily for agricultural uses. The basin area controlled by major dams (not including the Lower River Diversion Dam) is about 1530 square kilometers, or 36 percent of the total basin area. Several smaller dams, constructed specifically for the retention of sediment, control about 130 square kilometers of mountain-front drainage between Ventura and the mouth of Piru Creek. Table 1 lists some pertinent aspects of control structures in the basin.

Because of the complicated control history in the basin and significant gaps in the streamflow data base, the strategy for analysis of the Santa Clara River was somewhat different than that used for the Ventura River. Basically, the estimated flow in the absence of control structures ("natural" flow) was calculated from the following equation:

$$\begin{aligned}
 \text{"Natural" Flow} = & \text{Measured Flow near the rivermouth} \\
 & + \text{Diverted flow at the Lower River Diversion} \\
 & \quad \text{Dam (LRDD)} \\
 & + \text{"Natural" flows of Piru Creek} \\
 & - \text{Lake Piru releases diverted at LRDD} \\
 & + \text{"Natural" flows of Castaic Creek} \\
 & - \text{Release flows from Castaic Reservoir}
 \end{aligned}$$

Bouquet Reservoir affects less than one percent of the total drainage area and its influence on the annual streamflow near the rivermouth was considered negligible. Release flows from Pyramid Lake are contained within Lake Piru; thus, only the Lake Piru release flows are pertinent to this analysis. "Natural" flows of Piru and Castaic Creeks are the inflows to Lakes Piru and Castaic, respectively, corrected for percolation between the dams and the rivermouth.

The measured flow near the rivermouth was available for 1928-32 and 1951-75 only; therefore, the flow for 1933-50 was calculated using the following steps: (1) "Natural" flows for the periods 1928-32 and 1950-75 were calculated according to the equation stated above; (2) the calculated "natural" flows were then correlated with flows measured for tributary streams (Piru and Sespe Creeks) that were also measured during 1933-50; and (3) the flows calculated from the correlation were then adjusted for diversions at LRDD for 1933-50. The final regression equation used for step (2) is given by

$$\hat{M} = 0.396 (SP)^{1.2} - 3.15$$

TABLE 1
Control Structures

Structure	Water Year of Initial Operation	Capacity (acre-feet)	Drainage Area Affected* (km ³)
Lower River Diversion Dam at Saticoy, California	1929	---	4131
Bouquet Reservoir	1934	36,500	35
Santa Felicia Dam (Lake Piru)	1955	109,400	1101
Pyramid Dam	1971	173,500	759**
Castaic Reservoir	1972	350,000	404

*Total drainage area of the Santa Clara River Basin = 4219 km².

**This area is also controlled by Santa Felicia Dam.

where \hat{M} is the predicted annual flow near the rivermouth, and SP represents the combined annual flows of Sespe and Piru Creeks, in million cubic meters (Figure 6). The correlation coefficient between M and $(SP)^{1.2}$ is 0.996.

To predict annual sediment discharge, a correlation was performed using annual discharge near the rivermouth as an input variable. The "best-fit" equation, which gives zero sediment discharge for zero water discharge, is given by

$$\hat{Q}_s = 1225 Q_w^{1.5038}$$

where Q_s is the predicted annual suspended sediment discharge in metric tons (tonnes) and Q_w is the annual water discharge in million cubic meters. The correlation coefficient between \hat{Q}_s and $Q_w^{1.5038}$ is 0.999, and the data and relation are plotted in Figure 7. As in the case of the Ventura River, sediment-discharge data are available only for a short period. Fortunately, the data represent a wide range of hydrologic conditions, including major flood events in 1969, eliminating the need for extrapolation of the sediment-discharge prediction curve.

On the basis of the calculated flows and sediment discharges, it was shown that during the years 1928 through 1955 human constructions reduced the discharge of suspended sediment to the ocean by only about six percent. With the completion of Lake Piru, the suspended-sediment discharge to the ocean was reduced about 37 percent for the period 1956-75 (Figure 8). The total calculated reduction in suspended-sediment discharge for 1928-75 has been on the order of 50 million tonnes. Grain-size analyses of suspended-sediment samples collected near the rivermouth indicate that an average of approximately 15 percent of the suspended sediment load is sand. Furthermore, an estimate of bedload transport by the U. S. Geological Survey in the 1975 water year indicates that the bedload (mostly sand-size material) was about 15 percent of the suspended-sediment load. By combining these figures, it is estimated that the total reduction in sand transport was about 15 million tonnes. Assuming a gross density of 1.6 tonnes per cubic meter, that quantity of sand would represent 9.4 million cubic meters, or a 94-kilometer section of beach, 100 meters wide and one meter deep.

SUMMARY

The studies to date on the major rivers of Southern California suggest that a different strategy must be employed in each case of reconstructing the flows that would have occurred in the absence of human constructions. Whereas the analysis of the Ventura River was relatively straightforward, the analyses of heavily developed rivers such as the Los Angeles, San Gabriel, and Santa Ana promises to be much more demanding. A preliminary count of control structures in the study area shows 311 water-supply and flood-control reservoirs, 589 sediment-retention structures, 77 sand-and-gravel mines, and 65 percolation basins among other facilities. The extent to which flow and sediment-discharge can be accurately estimated is therefore conditioned by (1) available data for these structures, and (2) knowledge of their

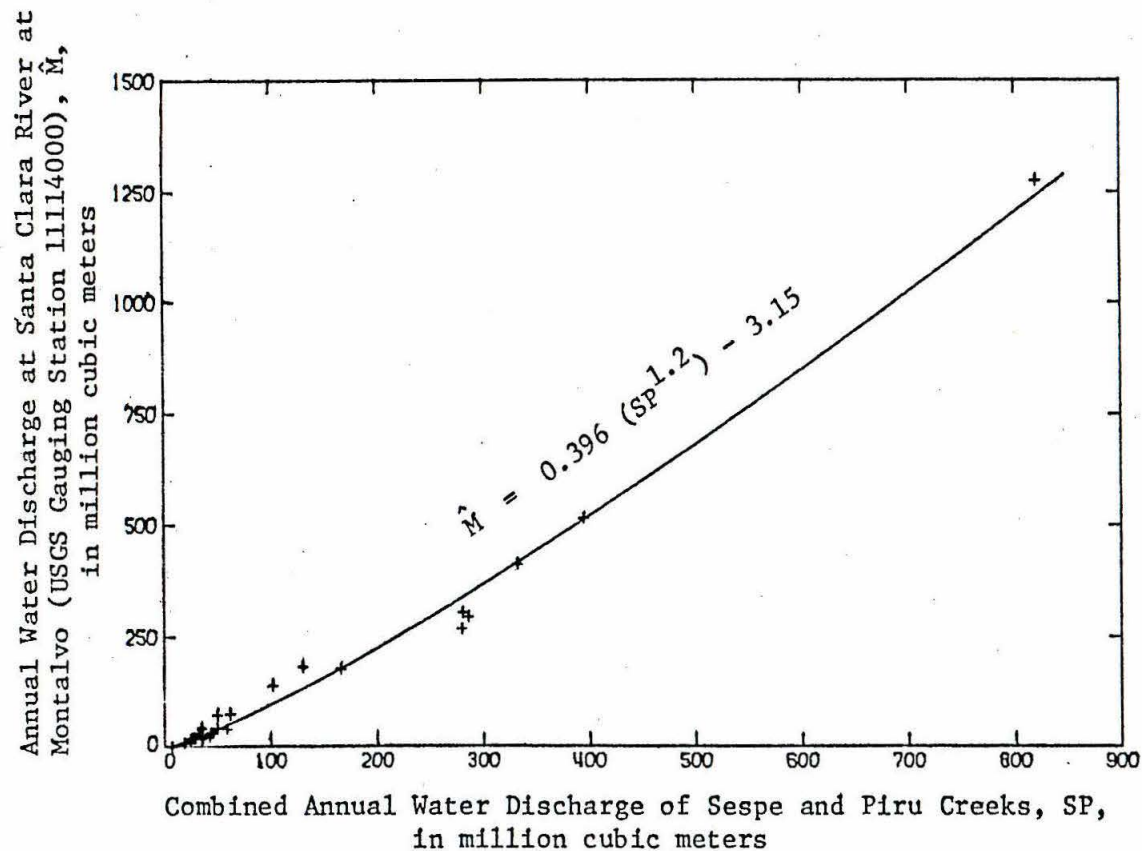


Figure 6. Correlation between annual flows near the Santa Clara Rivermouth with combined "natural" annual flows on Sespe Creek and Piru Creek for the period 1928-32 and 1950-75

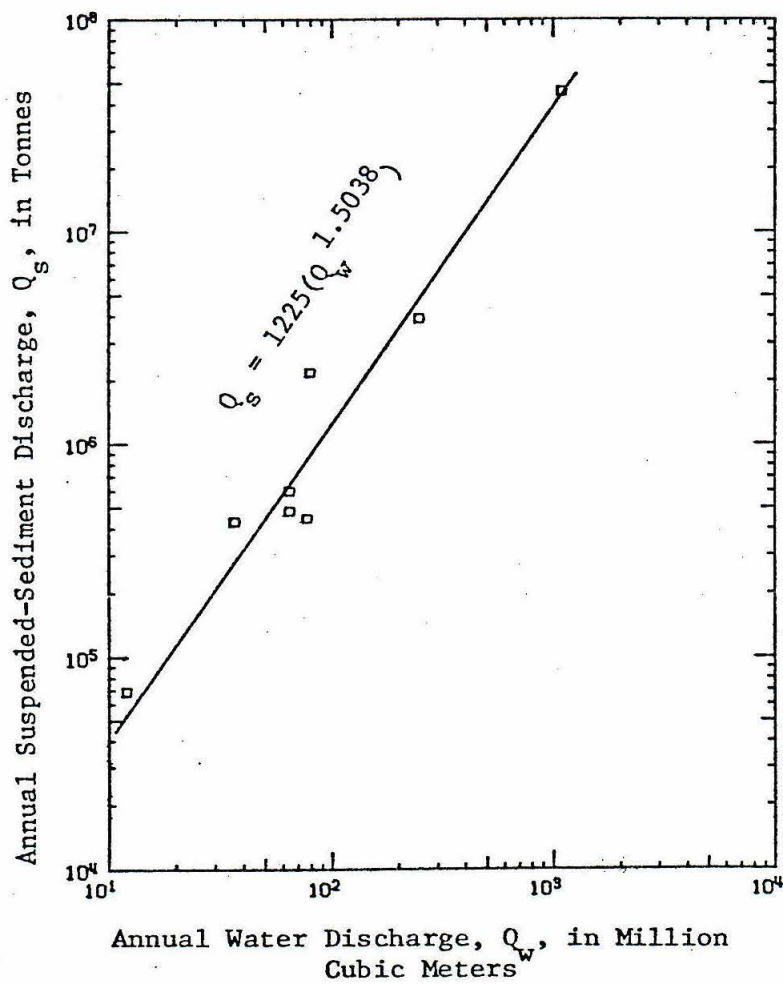


Figure 7. Sediment-transport relation for the Santa Clara River (USGS Gauging Station 11114000) for water years 1968-75

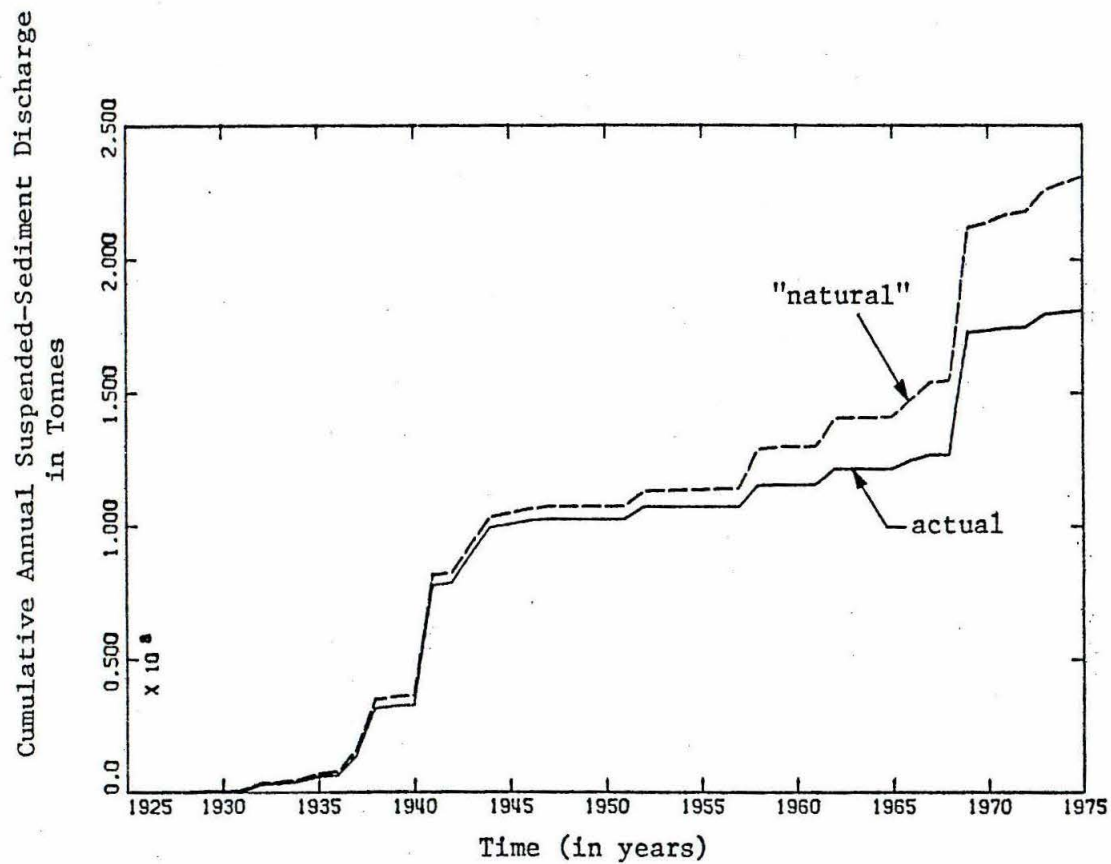


Figure 8. Cumulative sediment discharge of the Santa Clara River near its mouth (USGS Gauging Station 11114000) under "natural" and actual conditions, 1928-75

operating procedures. The accounting for these data and procedures, partly exemplified in the Santa Clara River analysis, promises to offer significant results with broad application to understanding the relation between inland construction and coastal processes.

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